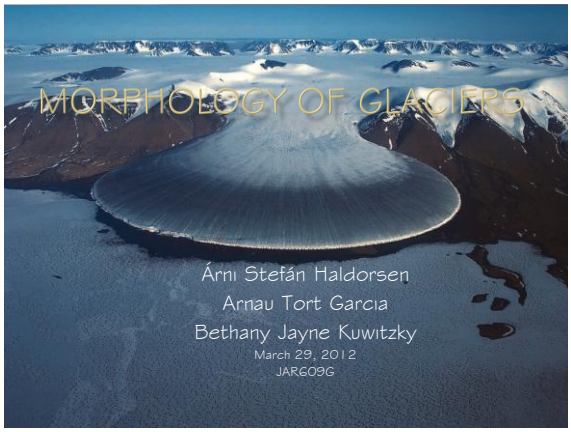


Classification of Glaciers

Glaciers can be classified into two groups depending on their extent:

- **Ice Sheets** (>50.000 km), continental scale
- **Ice Caps** (<50.000 km)

Ice sheets can be…

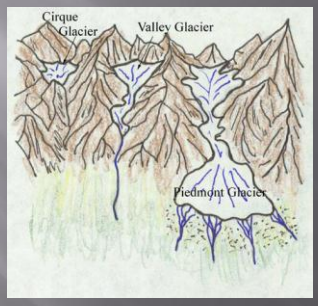
- **Land-based** (most of the base lies above sea level)
- **Marine-based** (most of the base lies under sea level). In this case they are called Ice Shelfs.

Depending on velocity…

- **Ice domes** (areas of relatively slow-moving ice)
- **Ice streams** or **outlet glaciers** (areas of relatively fast-moving ice). Ice streams can be confined by topography or by **ice rises** (surrounding areas of relatively slow-moving ice)
- **Ice shelfs**: where ice streams or outlet glaciers meet the sea. The sea is an inconfined area, therefore, they are areas of relatively slow-moving ice.

Depending on shape…

- **Ice fields**. In this case, the flow in influenced by topography (no dome-like shape)
- **Cirque glaciers**. They are located within a semicircular baisin at glacier heads.
- **Valley glaciers**. They are elongated (ice is flowing down the valley).
- **Piedmont glaciers**. They form when a valley glacier reaches an unconfined plain.
- **Transection glaciers**. They are a system of interconnected valley or cirque glaciers.

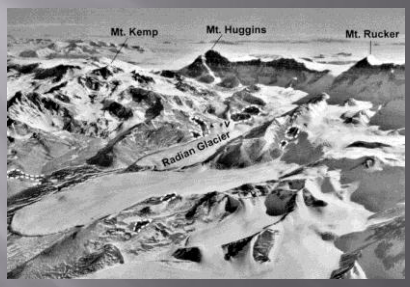


Southern Patagonian Ice Field

Malaspina glacier in south-east Alaska (piedmont glacier)

Cirque Glacier in Svalbard

The Aletsch Glacier in Switzerland (valley glacier)

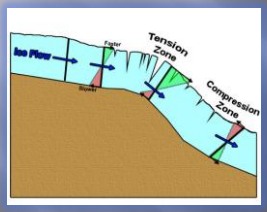


Transection glacier (transantarctic mountains in Southern victoria land)

CREVASSES AND THE MORPHOLOGY OF GLACIERS THAT CAUSE THEM

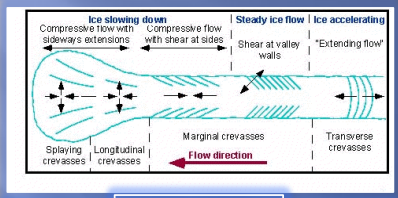
Glacier in Alaska, US

How do crevasses relate to the flow of glaciers?



- The bed underneath a glacier is not a uniform surface.
  - As the ice slides over the bed, it deforms in order to continue on its path.
- The entire glacier does not move at a uniform velocity.
  - When changes in velocity occur, extensional forces occur causing the ice to form fractures.

Types of crevasses



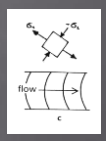
Longitudinal Crevasses
Longitudinal crevasses appear when the glacier is slowing down or spreading out.

Marginal Crevasses
Marginal crevasses occur when the glacial ice slides past the surrounding landscape, (lateral moraines, medial moraines, boulders, núnatakks, etc), and the ice is temporarily stuck by friction.

Transverse Crevasses
Transverse crevasses form when the glacier slope steepens suddenly. This can occur over a cliff, or over a large boulder.

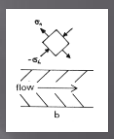
Let us take it a bit further...

Transverse crevasses in on the Pers-gletscher glacier in Switzerland



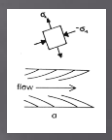
A TRANSVERSE crevasse is orientated perpendicular to the long axis of the glacier. This means that the stress perpendicular to the flow of the glacier is of smaller magnitude than the stress parallel to the flow of the glacier.

Marginal crevasse on Mt. Rainer



A MARGINAL crevasse is orientated at a 45° angle to the margin and is entirely due to lateral friction. This means that the greatest stress is shear stress from the margin which causes the crevasse to form at this angle.

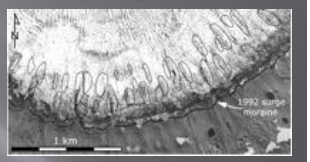
A longitudinal crevasse from the East Twin Glacier in Alaska

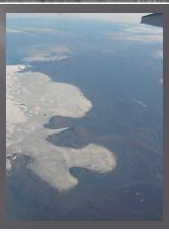


A LONGITUDINAL crevasse is orientated parallel to the direction of the flow of the glacier. This means that there is shear stress and compressive stress. As the glacier continues to flow down onto a flat plane, it spreads out.

Radial Patterns

At a glacial snout, there is an obvious radiating pattern to the crevasses. This occurs because the flow lines are diverging which causes tension parallel to the glacier margin which opens crevasses perpendicular to the margin.



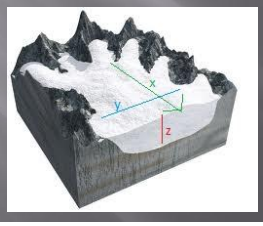


Múlajökull, Hofsjökull

$$\sigma^2-(\sigma_{xx}+\sigma_{yy})\sigma + (\sigma_{xx}\sigma_{yy}-\tau^2_{xy})=0$$

Because the glacier surface is planar....

- x-axis → in the direction of flow
- y-axis → in the direction across the glacier perpendicular to flow
- z-axis → in the direction perpendicular to the surface, towards the bedrock



$$\sigma^2-(\sigma_{xx}+\sigma_{yy})\sigma + (\sigma_{xx}\sigma_{yy}-\tau^2_{xy})=0$$

- $\sigma_{xx}, \sigma_{yy}, \sigma_{zz}$ → normal stress
- $\tau_{xy}, \tau_{yz}, \tau_{xz}$ → shear stress

- σ_1 → maximum
- Usually one of the 2 stresses will be compressive and the other tensile
- Crevasses form where σ_1, defined by the bulk stress exceeds the effective tensile strength of the ice.

Why do crevasses form the shape they do?

Crevasses have sharp tips because of the force from the far-field stress is not able to be transmitted across the fracture, so the stresses near the end are intensified.

Taku Glacier, Alaska

Bergschrund

Oberer Grindelwaldgletscher, Bernese Alps, Switzerland

- From the German term *Mountain Cleft*
- Irregular crevasse.
- Occurs when a moving glacier detatches itself from a stagnant peice of ice.
- Often extends to the bedrock.
- In a longitudinal glacier, the bergschrund occurs at the top of the glacier at a right angle to the flow.

Rift

- A tensional fracture through the entire thickness of an ice shelf.
- Can have significant effect on the dynamics of an ice shelf.
- Propagate from sides into the shelf.
- Contributes to calving.

Rift in Pine Island glacier ice shelf. Picture taken 18. okt 2011.

Depth of crevasses

- For temperate glaciers crevasses are usually no deeper than 25-30 m (80-100 ft).
- For a dry crevasse the depth can be calculated as:

$$d = \frac{2}{\rho g}\sqrt[n]{\frac{\dot{\epsilon}}{A}}$$

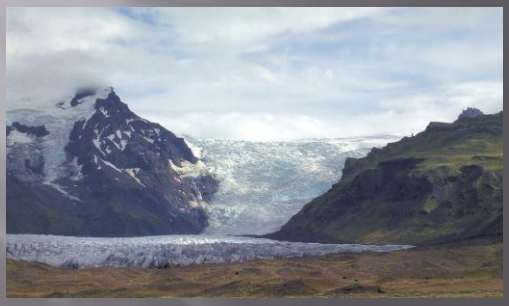
- This relation is a great simplification and is e.g. not valid for water filled crevasses where pressures are higher nor does it include fracture toughness.
- A formula derived by van der Veen gives a much greater depth, even as much as 2.5 times deeper.

Relation?

All of these crevasses occur because the glacier is constantly moving which in turn means the glacier is constantly being morphosed.

http://highered.mcgraw-hill.com/olcweb/cgi/pluginpop.cgi?it=swf:640:480:/sites/dl/free/0073524158/104251/12_01.swf::Crevasse%20Formation%20in%20Glaciers

Icefalls



Icefalls

- A part of a glacier where the flow of ice is rapid and surface heavily crevassed.
- Usually form where a glacier falls of a pronounced step in the bedrock and/or moves through a narrow passage.
- Rapid acceleration of ice.
  - First massive transverse crevasses form.
  - Total breaking of the ice.
- Below the icefall the ice slows down and pressure closes crevasses, possible formation of pressure ridges.

Breaking of ice

- Speed difference can be up to an order of magnitude.
- Faster than plastic deformation can happen therefore the ice breaks completely.
- The ice breaks up completely making the surface very chaotic.
- All lamination is destroyed in the process.

Ogives

Svinafellsjökull, Vatnajökull

- Alternating bands of dark and light ice that occur as thin crests and valleys
- Only below icefalls
- Curved foward due to the different velocities between the center of the glacier and the sides due to the lateral moraines and topography edges
- Each differently colored band is due to seasonal variation

Seracs

- Point on a glaicer where mulitple crevasses meet to form a lumpy surface.
- The term comes from a type of ricotta cheese.
- Can be very large, often the size of a small house.
- Extremely unstable.
- Often included in icefalls, or on the lower edge of a hanging glacier.
- Piz Roesg; Lyskamm; Kanchenjunga
- Serac on K2 responsible for 8 deaths in one incident

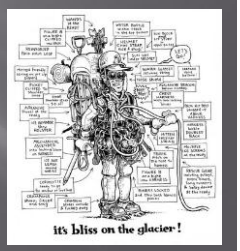
Franz Josef Glacier in New Zealand

Travelling on ice

- In a vehicle
  - Super-jeep
  - Snowmobile.
- On foot:
  - On snow (accumulation area)
  - On hard ice (ablation area)

Travelling on ice

- Proper equipment includes:
  - Crampons
  - Ice axe
  - Harness
  - Crevasse resque equipment
  - Food and clothing as in a normal hike.



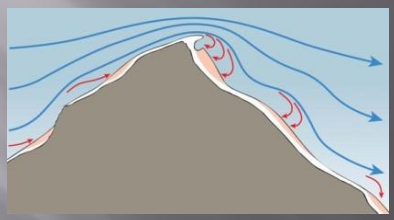
Dangers on glaciers

- Falling things:
  - Avalanches
  - Seracs
  - Cornice
- Falling into things:
  - Cauldrons
  - Crevasses

Snow covered ice

- On foot or on skis.
- Snow covers crevasses and cauldrons.
- Crampons may not be necessary but roped travel recommended, especially in known crevasse areas and in late summer.

Cornices



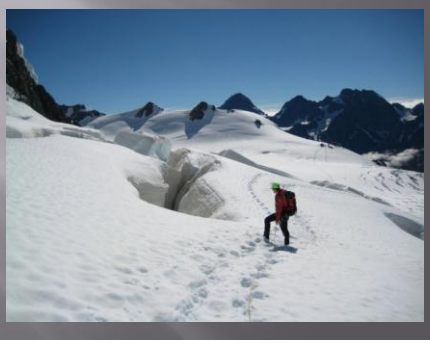
- Rebound mass: $G = 3.0(V-2.1)^2$ [g/m²s]
- Drift rate: $Q = 0.03(V-1.3)^3$ [g/ms]

Cornices

Snow bridges

- When cornice grows to reach accross a crevasse.
- Possibly hides the crevasse underneath and makes surface seemingly unbroken.
- Thickest near edges of crevasse, thinner in the middle

Snow bridges



Avalanches

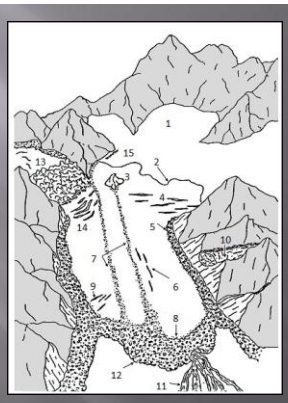
- Two main categories
  - Slab avalanches -
  - Loose avalanches – often fresh snow
- Most avalances occur in 30-45° slopes (most in 35-40°).

On hard ice

- Dangers are clearly visible, i.e. not snowcovered.
- Roped travel not recommended.
- Ice can however be slippery so crampons are recommended and often necessary.
- Seracs can fall without warning.
- Note that the ablation zone can be covered by snow during winter.

But it's not all bad...

...there's some fun to be had



Problems

- What effects does it have on a crevasse if it is filled with water?
- Temperature affects the mechanical properties of the ice, sustained low temperatures can...
  a) make crevasses bigger and seracs more stable.
  b) stop the flow of ice by freezing it to the ground.
  c) make crevasses smaller and cauldrons bigger.
  d) make crevasses bigger and seracs unstable.

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